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Project funded under the
Socio-economic Sciences and Humanities

Finance, Innovation & Growth (FINNOV)

Innovation in Venture-Capital Backed Clean-Technology Firms in the UK

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Abstract:

Driven by political pressures to cut down CO2 emissions and to find cheaper and renewable alternatives to fossil fuel based technologies, the clean technology sector (cleantech) has risen as an important target for VC investments in recent years. Using a broad definition of cleantech aimed at alternative energy production and/or providing solutions to environmental problems (Cooke 2008), this paper provides an initial exploration of the relationship between innovation and venture capital (VC) funding for 239 UK firms. Our analysis is based on a unique combination of three datasets; (1) FAME, (2) UK Intellectual Property Office patent data and (3) Cleantech Network's Venture Investments data. We find that the majority of VC backed UK cleantech firms do not patent or patent very little. This initial research suggests that the venture capital sector may not be supportive of radical new cleantech innovation; a potential concern for the UK's vision of achieving a low carbon economy.

Key words: Venture capital, clean technology; patents; innovation
JEL classification: G24, Q55

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1. Introduction

During recent decades, the availability of venture capital financing has grown rapidly, driven by the demand for equity based finance from entrepreneurial businesses in regions with a strong technology focus, such as Silicon Valley or Cambridge (UK). Hence, venture capital (VC) is considered a crucial factor for the development of emerging technologies providing risk capital to innovative new projects where high risks, long development times and significant costs of innovation make traditional forms of finance inappropriate. As such, VC is expected to act as 'technological gatekeeper' having a unique view of the emerging opportunities with the relevant experience to understand what makes a successful firm, allowing them to select opportunities that provide an appropriate commercial risk to return balance (Florida and Kenney 1988; Gompers and Lerner 2001; Pisano 2006). This paper considers the role played by VC in promoting a key newly emerging UK sector, the Clean-Technology.

The Clean-Technology sector, or cleantech, as it is commonly referred to, is a sector that has received increasing VC activity over the recent years. While the economic recession has led to a significant decrease in VC funding across sectors in 2009, cleantech was least affected by the adverse economic conditions, accounting for roughly 25% of all VC investments worldwide and 20% of VC investment in the US (Baker 2010; Thomson 2010).

Yet, despite being the 'new target' of VC activity, the characteristics of this sector and the role of VC in promoting cleantech innovations have not been discussed in either the VC or innovation literatures. Thus, this paper offers a preliminary analysis on the recent development of this industry, and provides insights into the activities of VC with the aim of understanding the relationship between the source of finance and underlying development of clean technologies.

We believe it is important to understand the dynamics of interaction between VC and innovation in the cleantech sector which is at the heart of UK's low-carbon future. The motivations of VC investment may not always fully support technology development. This is especially the case when innovation involves significant development times that do not 'fit' within the usual five or ten year venture fund timelines. The need for long-term, large-scale investments into alternative clean technologies and their infrastructure raises concerns to whether venture capitalists would be willing to support the most innovative cleantech activities. Indeed, early signs from 2009 suggest that VC has shifted its focus to funding cleantech investments with less than 2 year pay-back periods. For example, more incremental innovations that deal with efficient energy use appear to be given priority over the cutting edge bio-fuels or advanced solar technologies (Baker 2010). Likewise, evidence on the close link between VC investment in the energy sector and the crude oil prices raises further concerns of the sustainability and continuity of VC investments into clean technologies (Deutsche Bank 2010).

The paper provides a background of VC investment in the UK cleantech sector by exploring a scattered literature that describes the development of the clean-technology landscape in relation to technology and investment patterns. Section 2 briefly describes the general framework within which VC operates and Section 3 concentrates on the role of VC in the cleantech sector using descriptive statistics. Section 4 is a description of the data and empirical methodology used in the paper. Section 5 analyses the VC-innovation relationship in the cleantech sector and finally Section 6 concludes with the policy implications of the findings.

2. Innovation and venture capital funding trends in the UK cleantech sector

Technology and radical innovation will play an important role in meeting the resource demands of economic development whilst minimising its environmental impacts (Bosetti et al. 2009). An awareness of the need for new sustainable and environmental technologies has grown since the 1970s (Shrivastava 1995) but investment into developing new clean and environmental innovation has been limited. More recently, evidence suggests that technologies in the renewable sector are gaining acceptance with double digit growth in some energy sectors even though the process of changing the overall energy system has generally been slow and uncertain (Jacobsson and Johnson 2000).

The paper is motivated by the observation that innovation in clean technologies has gained momentum since 1980s with the growing political emphasis on sustainable economic development. The UK has risen as one of the most innovative countries in clean technologies starting from 2000 despite its role as a laggard in early 1990s (Martin and Wagner 2009). While there are noteworthy studies that examine UK innovations in clean technologies and the determinants of these innovations (Green et al. 1994; Klaassen et al. 2005); the literature has not specifically explored the activities and the innovative potential of promising UK cleantech firms that have qualified to receive VC funding. Likewise, the role of VC funding in promoting cleantech innovations is not an area that has attracted attention in either of the current innovation or VC literatures.

Although a commonly used investor term suggestive of a single type of activity, the sector is comprised of a wide range of technology covering a variety of applications broadly aimed at alternative energy production or providing solutions to environmental problems (Cooke 2008; BVCA 2009). The cleantech sector is still at very early stages of its evolution and it is less clear to what extent it can be presented as an integrated sector of activity. It covers a range of different technologies, such as solar, nuclear, wind and marine energy generation; the production of low carbon fuels, buildings, vehicles and electronics, as well as efficient technologies related to traditional oil derived fuels (BIS 2009).

Investments in cleantech infrastructure and R&D have increased in response to government commitments to cut down the carbon emissions by around one-third by 2020. The UK government allocated a sum of £405 million towards this cause in 2009 (HM Government, 2009). In line with the increased investments, Cullen (2009) indicates that the level of global patenting increased by threefold in the solar, wind and marine technology areas comparing the periods of 1997-1999 and 2006-2009 across various countries.

According to Cullen (2009), the UK's cleantech innovation appears to be reliant on smaller firms and contributions from the academic sector. In contrast to most other countries, large UK firms do not appear to be as active in patenting clean technologies. More importantly, a recent study suggests that the cleantech ideas patented by large multinational firms have on average taken 24 years to reach the mass market- a far too lengthy time period in the shadow of climate change and the predicted increases in global temperatures (Lee, LLiev and Preston 2009). Small firms have been shown to play an important innovator role in the early stages of new industries during which the innovations are more radical and where industry standards are not yet established (Klepper 1996). Thus, on this basis, venture capital could provide critical financial support and business mentoring to an emerging innovative sector.

Broadly, the innovation and finance literature concludes that venture capital is supportive of innovation within firms (Kortum and Lerner 2000; Hellman and Puri 2000; Da Rin and Penas, 2007) suggesting that VC should be especially important for young and small firms in emerging sectors such as the cleantech. The strong presence of small firm innovation in the cleantech sector and the increased perception of commercial prospects have drawn investors towards supporting smaller innovative UK cleantech firms. A recent survey of investor attitudes by Deloitte (2009), found that 60% of investors expected to increase their exposure to cleantech investment in the next three years.

In the face of declining venture capital activity across sectors, members of the British Venture Capital Association increased cleantech investment to £1.3 billion in 2008 (BVCA, 2009). The UK government also recognizes the need to maintain an economic environment favourable to entrepreneurship in the cleantech sector and has already taken a proactive step to stimulate the supply of venture capital to the low carbon energy sector through several public initiatives such as the newly introduced Energy Technologies Institute (www.energytechnologies.co.uk). A detailed breakdown of VC investment in UK cleantech firms is shown in Table 1.

[Table 1 about here]

Based on Table 1, energy generation, storage and efficiency are the leading areas of investment activity in the UK, taking a total of $1027m during the period analyzed. Figure 1 shows the breakdown of industrial shares of VC investment using the same data. Comparing the activity of different primary industries throughout the period shows no single investment area has maintained priority. Over the period, applications in transportation and energy storage have given way to investment in energy generation whilst other application areas such as recycling, air and environment, and water show a volatile trend in their share of investment activity. The herfindahl concentration ratio in Figure 1, based on investment activity across 34 secondary industries[1] during the period, also shows a diffusion of investment across industries with time, such that even within a particular primary industry an increasing variety of applications compete for funding.

[Figure 1 about here]

3. Empirical Approach

In the absence of previous research examining the relationship between cleantech innovation and venture capital funding, we use our discussion of the literature to guide an exploration of the cleantech sector. The risks resulting from investing in new technology in an emerging industry may be too large for many venture capitalists, and may restrict the development of the most radical and urgently needed innovations in the cleantech sector. Understanding which types of innovations and innovators are targeted by VC investors will help to identify areas of market failure and hence highlight other areas that require non-VC type innovation funding.

In this paper, we use innovative activity (measured by patenting and citations data) to explore the differences in characteristics (in terms of size, turnover and amount of VC funding received) of innovative and non-innovative cleantech firms. Patenting is a widely used measure of innovation in VC literature, capturing firm's attempts to build monopoly profits from their innovations. Kortum and Lerner's (2000) extensively cited research paper uses an industry analysis of R&D and patenting activity in the US to show that venture capital investment was more productive than corporate R&D in producing patents. They found, on average that VC is nearly 3 times more effective at stimulating patents than corporate R&D. Ueda and Hirukawa (2008) support the Kortum and Lerner (2000) conclusions, finding that venture capital is associated with firms that have more original patents, as measured by the technical breadth of the patents being cited in an application, indicating venture capital is used to finance more radical innovation.

We also examine several characteristics of investor activity in the cleantech sector. We analyse the time lag between patenting and venture capital funding to provide an indication of whether investment has led or followed innovation. Then we analyse investors' portfolios looking for evidence of specialisation in supporting innovative (patenting) vs. non-innovative (not patenting) firms using basic statistical tests.

3.1 Data and Methodology

The analysis in the paper is divided into two parts; firstly we examine the patenting activity of cleantech firms using descriptive statistics and t-tests and secondly we look at investors' behaviour according to the patenting activity in their portfolio using summary tables and t-tests.

The data used in this paper is based on the Cleantech Network database of venture funded firms in the UK. We record the total investment received by firms funded by venture capitalists between July 2001 and September 2009[2] for firms headquartered in the UK. We match these firms to the FAME database to check the firm status and obtain available data on the most recent revenue, profit and employment figures. We also collected data on whether a firm in our sample was granted a patent between 1963 and September 2009 in the UK Patent Office and recorded all characteristics (e.g. patent number, application and grant dates, number of citations made and received, International Patent Classes the patents are assigned to) of the patents assigned to these firms[3].

The literature raises a number of methodological concerns about using patent data as an innovation indicator. For example, not all inventions are patentable, so patent analysis provides a partial view of innovation in a particular industry. Comparing patenting activity across and within industries can be difficult as the propensity to patent can vary, even between firms (Griliches 1990). Industries like pharmaceuticals and chemicals (i.e. science based sectors) are known to use patents most frequently while other industries have lower propensities to patent (Chabchoub and Niosi 2005). Moreover, it is not always clear how one can correctly assign a patent to an economically relevant industry (Griliches 1990).

To address these concerns, we limit our interpretation of patent data to simply a 'signal' of innovative activity rather than a strict indicator of innovative products and processes. We distinguish between firms that have applied for a patent and those that have not. While we do not claim that firms lacking patents are non-innovative; we argue that patenting firms are in general more innovative and potentially in a better position to exploit the returns of these innovations through the intellectual property rights.

The most important challenge in using patents as an innovation indicator, however, is the extremely skewed distribution of the value of patents (Silverberg and Verspagen 2007). Patent counts are considered noisy measures of innovation as the quality of patents varies widely even within the same industry and most patents "include minor improvements of little economic value" (Griliches 1990, 1666). To deal with the heterogeneous quality of patents in our sample, we filter out the less important patents by weighting every patent by the number of citations it has received since its grant date (Jaffe 1990). The main assumption is that more important patents get cited more frequently. Therefore, weighting patents by the number of citations received distinguishes more important patents from less important ones and reduces the noise associated with using only raw patent counts (Jaffe and Trajtenberg 2002). Specifically, part of our analysis focuses on 39 'highly cited patents' (HCP) that have received a minimum of 5 citations. These HCP constitute a good representation of the most important innovations conducted within our sample while also allowing us to distinguish firms further based on the importance of their innovative activity.

4. Analysis

4.1 Innovation characteristics of the UK clean-tech firms

Table 2 summarizes the characteristics of patenting activity among the 239 firms in our sample. Around one third of the firms have been granted at least 1 patent between 1963 and 2009 while two thirds of the firms do not own any patents. Among the 80 firms that own at least one patent, 25 firms own only one patent and 56 firms own less than six patents. 24 firms (coinciding to 10% of patentees) own more than five patents.

[Table 2 about here]

Table 3 shows a summary of firms' size (proxied by turnover and employment) and investment history (proxied by external investment received and the total rounds of investment received). We compare patentee firms with their non-patentee counterparts. T-tests confirm that the means of total investments and total rounds of investment are significantly higher for patentee firms. Interestingly, the turnover of patentee firms are significantly smaller compared to non-patentee firms, however the employment in patentee firms is not significantly different. These suggest that innovative firms, despite being smaller, have been more successful in attracting VC investments.

[Table 3 about here]

As previously discussed, the number of citations received by a patent, signals the importance of the innovation. Hence, we expect more highly cited patents to account for more important and radical innovations (Jaffe and Trajtenberg 2002). Moreover, evidence confirms that citation counts are positively correlated with economic value of patents suggesting that more cited patents are more important (Hall et al. 2005).

The 80 patentee firms in our sample have a total of 471 patents and the number of citations per patent ranges between 0 and 41. The average citation per patent in the sample is 1.87. Table 4 shows the distribution of citations received for the patents in the sample. This is a clear indicator of the right skewed distribution of the value of patents as almost half of the patents have not received any citations and only 8.28% of the patents have received 5 citations or more.

[Table 4 about here]

4.2 Characteristics of the UK clean-tech firms with highly cited patents

In this section we focus on the 39 *'highly cited patents'* (HCP) that have received a minimum of 5 citations, examining both their technology characteristics and how they relate to our population of cleantech firms. Our investigations show that these 39 patents belong to a total of 16 companies where three firms account for the 64% of the 39 HCP. Interestingly, only 4 of these 16 firms are among the top 10 firms with the highest number of patents in the whole dataset. This further confirms that the quantity of patents a firm holds is not always highly correlated with the quality of its patents.

We find that the 39 highly cited patents include 140 different International Patent Classes (IPC). As shown in Table 5, the most concentrated IPC classes[4] relate to combinations and adaptations of machines and engines for special use in the context of power stations; use of tide energy (and liquid flow) as well as electric generators; the manufacture of fuel cells; and valve-gear and valve arrangements (often used in internal combustion engines).

[Table 5 about here]

In Table 6, we compare the characteristics of the firms that own at least one HCP with the patentees that do not own any HCP. As the comparisons suggest, HCP firms have larger patent portfolios compared to the rest of the patentee firms and received higher levels of investment funding over a higher number of rounds. T-tests reveal that the differences in the amount of total investment funding received by HCP firms and the rest of the patentee firms are not significant, although HCP firms received funding over more rounds. We also find HCP firms are not statistically different in size from the rest of the patentees in employment or turnover.

[Table 6 about here]

4.3 Investment timing

A key question in the literature is whether investment supports very early stage innovation, or simply commercialises the innovative output of new firms. To gain an insight into the timing of innovation and investment in the cleantech sector, we use patent records to establish whether venture capital leads or follows innovation. We examine the 80 firms with patents granted and measure the number of years between the patent application/grant dates and the first round of venture capital investment[5]. Figure 2 shows the distribution of firms in the sample according to the timing between first successful patent application (2a) /first patent granted (2b) and the first round of venture capital. On average a firm receives the first round of investment 1.9 years after the first successful patent application or 0.5 years after the grant date, indicating on average that investment follows the receipt of a patent. However the distributions show that 16% of firms received investment in the years leading up to a patent application, suggesting some investment is used to finance early stage innovation processes. A far higher proportion of firms (48%) received investment prior to being granted a patent. As a substantial amount of innovative effort is required to apply for a patent in the first instance, the investment in the period between patent application and grant is likely to follow rather than lead innovation.

[Figure 2 about here]

4.4 Investor statistics

In this section we examine the relationship between patenting activity and investor behaviour. Specifically, we look at the specialisation of investors according to whether they actively invest in patenting firms and to the assignees of highly cited patents. We seek to understand whether patenting has implications for the type of investors involved in funding.

Our analysis is based on the activity of 275 investors who provided finance to the 239 firms in our sample. The distribution of investment activity is skewed; a minority of investors are highly active, whilst the majority invest in a small number of firms. We use the investment history for each investor in the cleantech sector to capture and analyse their 'cleantech portfolio'.

Specifically we measure the size of portfolio in terms of the number of firms, the total value of each round participated in, and the average round size per portfolio firm (PF). We estimate the approximate contribution of each investor, using information on the syndicate size to calculate each investor's overall commitment, and commitment per firm[6]. We repeat this analysis for rounds at the early stage (seed and first round deals), to provide more detail on investors' preference for risk and early stage innovation[7].

We examine the 'spread' or coverage of each investor's portfolio according to the 11 different primary industries as shown in Table 1. We also analyse the innovative characteristics of each investor's portfolio, analysing the patenting behaviour of portfolio firms, measured as the total number of patents in the portfolio, the average number of patents per firm and the proportion of patentee firms in the portfolio. We provide similar statistics for each investor's portfolio based on citation information.

4.5 Investor differences based on patenting in the investment portfolio

The results in Table 7 indicate that investors supporting patenting firms are more active overall, having larger portfolios and participating in larger total financing rounds. The group of investors involved with patenting firms are also more active at the early start-up stages (seed and first round).

[Table 7 about here]

However, the t-test comparing average round sizes for the seed and first round investments, only shows a significant difference between the portfolios of the two investor groups at the 10% significance level. This gives some support to the observation that VC supports innovative firms with the concept of risk capital. Yet, the absence of a significant difference between the average overall investment rounds, suggests investors in patenting firms, although more active overall, are no more likely to invest more in any given opportunity.

Finally investors supporting patenting firms fund opportunities across a wider range of industries than their counterparts indicating a relatively generalist approach to investment even for investors who support innovators. This is reflective of nature of the sector as shown in Figure 2[8].

4.6 Investor differences based on ownership of highly cited patents (HCP) in the investment portfolio

Table 8 shows summary statistics for the 140 investors that supported at least one patenting firm. Table 8 is split between 91 investors that have not financed a firm with a highly cited patent (HCP) and the remaining 49 that have. The t-test results show that investors supporting firms with HCP are more active in cleantech, with larger portfolios in terms of the number of firms and the amount of overall investment. Investors backing HCP firms also had significantly higher statistics for the innovation (patent and patent citation) measures. An exception was that both investor groups had a similar proportion of patenting firms in their portfolio.

However, despite the higher innovation statistics for investors with HCP portfolio firms, there is little evidence that firms in either investor group receive different amounts of funding (at the round or firm level). Likewise, differences in early stage investment are statistically insignificant between the two investor groups.

In line with the results of Table 7, Table 8 suggests that investors who support firms with higher numbers of patents and patent citations, tend to have a portfolio covering a higher number of industries.

[Table 8 about here]

The results in this section have shown specific differences between investors based on their preferences for innovative firms. Investors associated with firms having patents and patent citations generally have a larger portfolio and pursue opportunities across a wider range of industries. Yet, although these investors are more active, this does not translate into larger amounts of funding per round or per firm for firms with patents or highly cited patents.

These findings are suggestive of experimental investor behaviour, whereby the largest investors operate a broad portfolio investigating many different opportunities. It is clear that investor portfolios show important differences according to the innovation characteristics of the selected firms. However, despite providing greater financial support for patenting firms at the earliest development stages, it is less clear whether investors are prepared to respond to signals of high quality innovation and reward this with greater levels of financial support.

5. Discussions and Conclusions

This paper presents an initial exploration of the relationship between cleantech innovation and venture capital activity. The absence of other studies in this area, and the relatively new resurgence of investment activity in this loosely defined technology area mean that we have provided a simple analytical overview of the innovation and investment dynamics in the sector.

Facing urgent environmental challenges, one would expect the cleantech sector to be operating on the frontier of the cutting edge renewable and environmentally friendly technologies. Yet, our results provide evidence for significant variation in the patenting behaviour of cleantech firms and the strategy of the investors. In the 239 VC backed firms analysed, we find the majority do not patent. Even firms with patents often have very small patent portfolios. Although the cleantech sector is still in emergence, our results suggest technological development may not be a critical part of cleantech firm strategy. It raises further questions about the types of firms and technologies the venture capitalists prefer to fund in the sector and whether this is well aligned with the UK Government agenda of transition to a low carbon economy.

Despite the slow phase of patenting activity, our results confirm that patenting is an important signal for attracting VC investment in the cleantech sector. The patenting firms in the sample attract greater levels of VC investment. In line with this observation, we also find that investors who have funded at least one patenting firm tend to be larger, provide more investment to the sector overall and are active across several industries. Hence, the patent signal attracts larger investors who have greater levels of investment activity at the early stages as well as contributing more on average in each early stage round.

Another indicator which confirms the lack of technological focus in UK's VC funded cleantech firms is the small number of patent citations received by these firms. Patent citations are indicative of the importance and high quality of the cited patents. In our sample, majority of patents do not receive any citations, indicating a low innovation quality across the cleantech sector. Highly cited patents are rather few and concentrated in a small group of firms.

Moreover, VC investment does not appear to favour firms with highly cited patents (and hence higher quality innovations) as these firms do not receive significantly higher levels of investment. In fact, VC investment to firms with highly cited patents is spread over a greater number of rounds. The use of investment rounds or *staging* is one method of reducing risk for the investor, as they have greater control over the flow of investment into the firm. This result suggests that higher quality and more radical innovations may be perceived as higher risk by investors and result in higher levels of scrutiny for the more innovative cleantech firms. For example, a managing partner of Frog Capital (a significant cleantech investor) recently commented in interview (NewNet 2010),

> "We believe our expertise sits in the commercialisation phase. We are not in the business of taking huge technology risks and betting on which technologies will grow in the hope of picking a winner. Rather, we favour consistency and that is why we believe our portfolio companies to be fairly safe bets."

In line with this statement, our results suggest investors appear to be experimenting with their investment models and avoid taking big risks associated with funding the most radical and risky cleantech innovations.

The cleantech sector has grown in response to a variety of demand related factors, including rising energy costs, increasing environmental regulation and growing political concern regarding climate change. As indicated in Stern Review on the Economics of Climate Change, low carbon and high efficiency technologies are required on an urgent timescale. The report further suggests that public funding into clean technologies would be especially beneficial to support sectors like electricity generation where clean technologies are struggling to gain a foothold. Our results provide evidence to support this view as only a minority venture capital investment has been directed at technology innovators, particularly those with more radical innovation, indicating a potential market failure. Hence, public funding could be especially important to support emerging innovation in the cleantech sector. Here more research is required to provide a comprehensive analysis of innovation activity in the UK's cleantech SME. To this end, we are currently conducting a survey of innovation in SME in the cleantech sector, with early results due in late 2010.

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[1] Industries defined as per Cleantech Networks. http://cleantech.com/about/cleantechdefinition.cfm

[2] The investment history to the end of November 2009

[3] Patents are indicators of innovative activity, for which the firm wishes to exclude potential rivals from copying an innovative idea, product or process.

[4] Specific IPC classes include **F03B** (003/00; 003/04; 011/00; 013/00; 013/10; 013/12; 013/26; 017/00 and 017/06)); **F01L (**001/02; 001/34 001/344 and 013/00**); H01M** (004/86; 008/02; 008/10 and 008/12)

[5] Data includes successful patent applications only.

[6] A round of £10m involving a syndicate of four investors, is estimated to represent a commitment of £2.5m per investor. This is an estimate as syndicates may involve uneven contributions depending on the share of the company each investor holds.

[7] Investment in start-ups is expected to be high risk because of the unproven nature of both the firm and any innovation being developed.

Table 1: Deal value by year and primary industry ($m)

	Deal year								
Primary Industry	2001/2	2003	2004	2005	2006	2007	2008	2009	Total
Agriculture	0.0	1.2	5.7	13.0	5.0	8.2	18.7	17.3	69.1
Air & Environment	0.5	1.4	2.2	33.2	20.8	15.5	18.4	0.7	92.6
Energy Efficiency	0.0	18.4	16.3	17.7	0.0	55.5	40.5	27.6	175.9
Energy Generation	21.0	8.7	29.5	76.5	81.4	143.2	153.3	73.8	587.3
Energy Infrastructure	0.0	0.0	0.0	3.7	0.5	1.2	6.5	4.0	15.9
Energy Storage	6.1	26.0	42.5	39.7	14.3	63.6	27.0	44.2	263.3
Manufacturing/Industrial	0.0	1.1	0.0	2.5	8.3	56.2	8.5	9.6	86.1
Materials	6.0	0.0	11.0	25.3	25.3	4.1	14.4	0.0	86.1
Recycling & Waste	0.0	0.8	7.7	18.3	21.5	18.8	44.8	27.6	139.5
Transportation	48.8	34.5	12.8	21.1	9.7	13.1	11.0	11.8	162.7
Water & Wastewater	0.8	0.5	1.1	1.8	3.2	3.8	6.6	14.1	31.9
Grand Total	83.2	92.6	128.7	252.7	189.9	383.0	349.6	230.8	1710.5

Source: CleanTech Network, collated by authors.

Table 2: Distribution of patents in the sample of UK VC funded firms

Patent analysis	Count (%)
Patentees	80 (33.4%)
Non-Patentees	159 (66.6%)
Firms with 1 patent	25 (7.6%)
Firms with 2-5 patents	31 (13%)
Firms with 6-10 patents	10 (4.2%)
Firms with 11-25 patents	11 (4.6%)
Firms with more than 25 patents	3 (1.3%)
Total Number of firms	239 (100%)

Table 3: A comparison of Patentee and Non-Patentee firms

Non-Patentees						
	Observations	***Mean***	***Std Deviation***	***Min***	***Max***	
Employee count	47	367.15	2048.1	1	14060	
Turnover (£000)	44	60820.92	255180.5	.24	1617300	
Investment (£000)	139	6.50	9.73	0.09	58.12	
Rounds count	139	1.43	. 93	1	6	

Patentees						
	Observations	***Mean***	***Std Deviation***	***Min***	***Max***	***Sig***
Employee count	21	31.24	31.13	3	124	
Turnover (£000)	28	1324.64	2685.19	13.91	12649	***
Investment (£000)	83	10.05	15.98	0.09	91.35	***
Round count	83	1.97	1.45	1	9	***

Note: *** 1% significance level, ** 5% significance, * 10% significance.

Table 4: Distribution of citations

	0 citation	***1 citation***	***2-4 citations***	***5-10 citations***	***11-20 citations***	***21 or more citations***
Number of Patents	228	113	91	27	9	3
%	48.41	23.99	19.32	5.73	1.91	0.64

Table 5: A comparison of the IPC classes for the 'highly cited patents' and the patents that cite these

	Machines or engines for liquid e.g water turbines (F03B)	**Fuel cells (H01M)**	**Valve gear (F01L)**	TOTAL
Highly Cited Patents: Share of IPC Classes	47.14%	14.29%	20.71%	82.14%

Table 6: A comparison of patentees based on ownership of HCP

HCP firms						
	Observations	***Mean***	***Std. Deviation***	***Min***	***Max***	***Sig.***
Patent count	16	11.69	13.37	1	57	***
Employee count	5	30.2	16.71	10	56	
Turnover (£000)	5	1810.21	2852.423	113	6880.333	
Investment (£000)	16	15.26	16.30	.59	47.03	
Round count	16	2.69	1.53	1	5	**

Patentees with No HCP					
	Observations	***Mean***	***Std Deviation***	***Min***	***Max***
Patent count	64	4.84	7.42	1	43
Employee count	15	31.56	34.89	3	124
Turnover (£000)	23	1219.09	2702.66	13.91	12649
Investment (£000)	64	8.80	15.78	0.09	91.35
Round count	64	1.81	1.39	1	9

Note: *** 1%, ** 5%, * 10% significance level.

Table 7: A comparison of investors according to the patents in their portfolio

Investors with no patenting firms in their portfolio

Variable	***Observations***	***Mean***	***Std Deviation***	***Min***	***Max***
Count of PF	135	1.23	0.63	1.00	6.00
Total round value	127	12.30	16.80	0.06	108.00
Round value/PF ($mill)	127	9.44	14.90	0.06	108.00
Approx. Commitment ($mill)	120	4.28	4.99	0.03	30.00
Approx. commitment/PF ($mill)	120	3.65	4.54	0.03	30.00
Primary ind.	135	1.14	0.39	1.00	3.00
Seed round value ($mill)	127	0.27	0.86	0.00	5.94
Ave. Seed round ($mill)	127	0.16	0.47	0.00	2.85
First round value ($mill)	127	1.97	3.88	0.00	20.90
Ave.First round ($mill)	127	1.57	3.48	0.00	20.90

Investors with at least one patenting firm in their portfolio

Variable	***Observations***[8]	***Mean***	***Std Deviation***	***Min***	***Max***	***Sig.***
Count of PF	140	2.47	2.66	1.00	20.00	***
Total round value ($mill)	137	21.50	26.10	0.36	159.00	***
Ave. round ($mill)	137	7.06	6.18	0.34	26.00	
Approx. Commitment ($mill)	130	7.39	9.87	0.12	65.00	***
Average commitment ($mill)	130	3.72	4.29	0.12	27.60	
Primary ind.	140	1.93	1.44	1.00	8.00	***
Seed round value ($mill)	137	0.90	2.00	0.00	11.30	***
Ave. Seed round ($mill)	137	0.29	0.69	0.00	3.20	*
First round value ($mill)	137	5.94	8.43	0.00	33.70	***
Ave.First round ($mill)	137	2.46	4.64	0.00	26.00	*

*Note: *** 1% , ** 5%, * 10% significance level.*

Table 8: A comparison of investors according to highly cited patents in their portfolio

Investors with no HCP firms in their portfolio

Variable	*Observations*	*Mean*	*Std Deviation*	*Min*	*Max*	*Sig.*
Count of PF	91	2.05	1.96	1.00	14.00	
Count of Patenting PF	91	1.23	0.56	1.00	4.00	
Count of patents	91	8.56	12.64	1.00	55.00	
Count of citations	91	6.80	11.61	0.00	65.00	
% Patenting PF	91	0.80	0.28	0.14	1.00	
No. of patents/PF	91	5.44	8.94	0.14	43.00	
No. of citations/PF	91	4.35	7.71	0.00	33.00	
Total round value ($mill)	88	15.00	16.50	0.36	66.80	
Ave. round ($mill)	88	7.04	7.00	0.34	26.00	
Approx. Commitment ($mill)	85	4.63	4.97	0.12	27.60	
Average commitment ($mill)	85	3.27	4.40	0.12	27.60	
Primary ind.	91	1.70	1.30	1.00	8.00	
Seed round value ($mill)	88	0.67	1.51	0.00	7.58	
Ave. Seed round ($mill)	88	0.31	0.75	0.00	3.20	
First round value ($mill)	88	5.13	8.37	0.00	33.70	
Ave.First round ($mill)	88	2.83	5.50	0.00	26.00	

Investors with at least one HCP firm in their portfolio

Variable	*Observations*	*Mean*	*Std Deviation*	*Min*	*Max*	*Sig.*
Count of PF	49	3.24	3.51	1.00	20.00	**
Count of Patenting PF	49	1.90	1.49	1.00	8.00	***
Count of patents	49	19.73	22.85	1.00	95.00	***
Count of citations	49	60.73	76.84	5.00	289.00	***
% Patenting PF	49	0.76	0.27	0.25	1.00	
No. of patents/PF	49	8.40	9.30	1.00	57.00	*
No. of citations/PF	49	36.70	61.90	1.00	214.00	***
Total round value ($mill)	49	33.20	35.00	0.00	159.00	***
Ave. round ($mill)	49	7.11	4.39	0.00	21.40	
Approx. Commitment ($mill)	45	12.60	14.00	0.00	65.00	***
Average commitment ($mill)	45	4.58	3.99	0.00	20.20	*
Primary ind.	49	2.35	1.60	1.00	7.00	**
Seed round value ($mill)	49	1.31	2.64	0.00	11.30	
Ave. Seed round ($mill)	49	0.25	0.58	0.00	3.15	
First round value ($mill)	49	7.40	8.41	0.00	32.70	
Ave.First round ($mill)	49	1.80	2.34	0.00	12.00	

Note: *** 1%, ** 5%, * 10% significance level

Figure 1: Shares of investment value and herfindahl index investment concentration

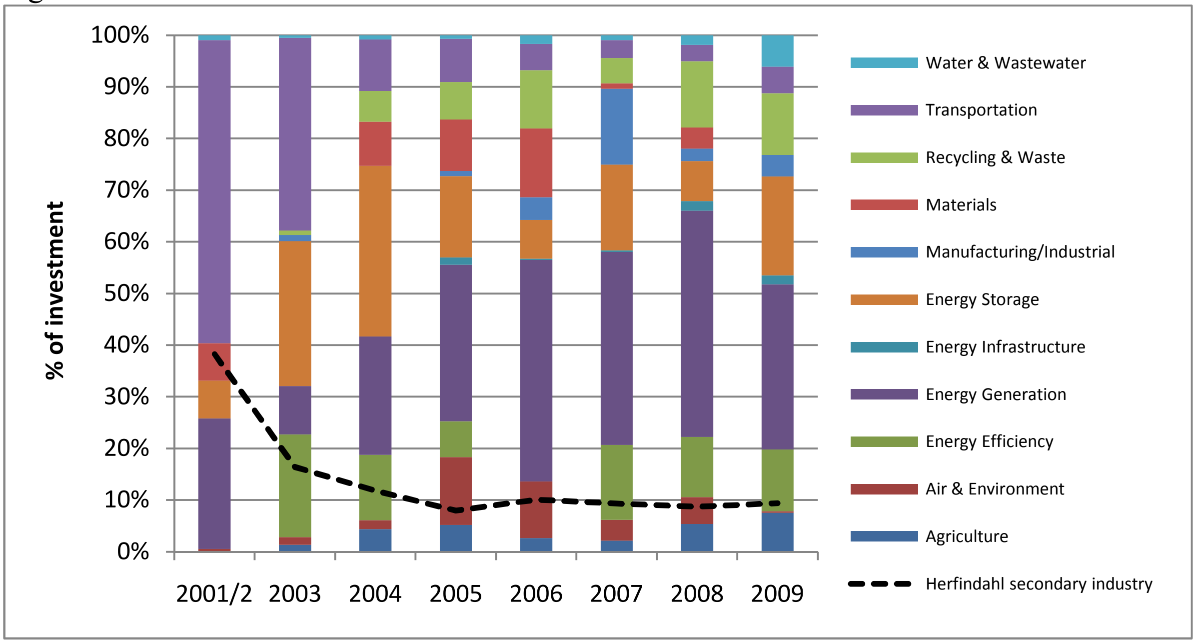

Figure 2a –Timing between patent application and first VC round

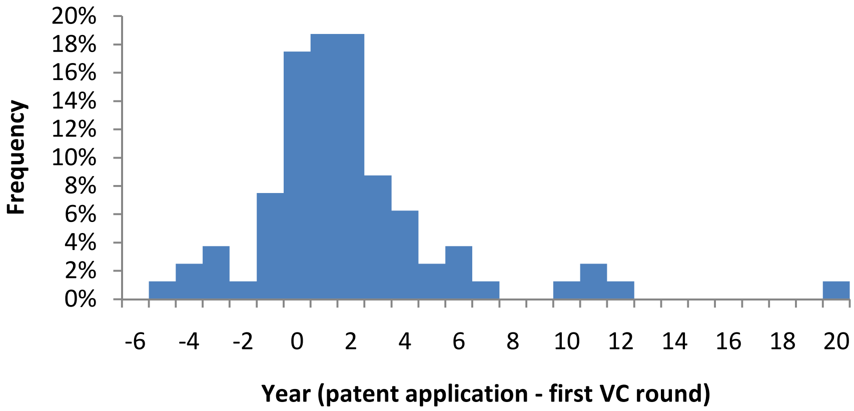

Figure 2b – Timing between patent grant and first VC round